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Simulation and characterization of encapsulated pressure sensors

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Abstract

Based on the necessity of encapsulating pressure sensors, a platform for qualification of encapsulation materials like silicone has been set up and verified. A simulation model describing the physics of pressure transfer was developed. First results prove the applicability of the simulation. For verification a sensor device was successfully assembled and tested in a test environment, optimized to ensure fast pressure load changes.

Simulation and test series data deviate less than five percent. The qualification setup presented in this paper is thus considered to be adequate for testing various materials and assemblies.

Keywords: pressure sensor; encapsulation; simulation

1. Introduction

Encapsulation of sensor systems for protection against environmental influences is usually required. Particularly medical applications often use some kind of soft silicone when pressure sensors need to be protected^{1,2}. A major problem concerning encapsulation of pressure sensors is the accurate pressure transfer. The softer the encapsulation material, the better the pressure transfer, but softer materials provide less protection and often provide non linear behavior in terms of conducting pressure. Harder materials provide better protection but are more complicated in handling. Defects like air entrapments are common and cause problems in the response behavior of the encapsulated sensor.

In order to gain more knowledge about pressure transfer in silicone and to examine the behavior of encapsulated pressure sensors more thoroughly, simulations were realized and verified by experiment.

2. System setup

2.1. Test device

At first a standard test device was designed to be analyzed in simulations and measurements. The test device consists of a pressure sensor and a spacer mounted on a PCB (figure 1, left). In this experimental series the absolute pressure sensor SM5108 from Silicon Microstructures, Inc. is used because the size is only 650µm x 650 µm and the full scale range (30 psi = 2068 mbar) of the sensor is adequate to the intended medical applications. The spacer is filled with three different types of silicone (Nusil Med-4930, Nusil Med-4950 and Nusil Med-6015) at different heights. This basic assembly is chosen to evaluate the quality of the simulation. The main aim is to establish a simulation basis to evaluate and optimize systems in further steps.

The experimental setup mainly consists of the pressure chamber where the test device is inserted and two reservoirs. Two fast switching pneumatic valves allow a fast change of pressure. For the purpose of comparability with verification experiments the pressure should be applied as a square function to the system. All simulations and measurements were carried out before and after encapsulation. A calibration of the system was performed with a reference sensor and the time required for a pressure

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change of 50 mbar in the chamber was detected to be 10 ms. This is sufficient for a representation of a rectangular function regarding the intended application.

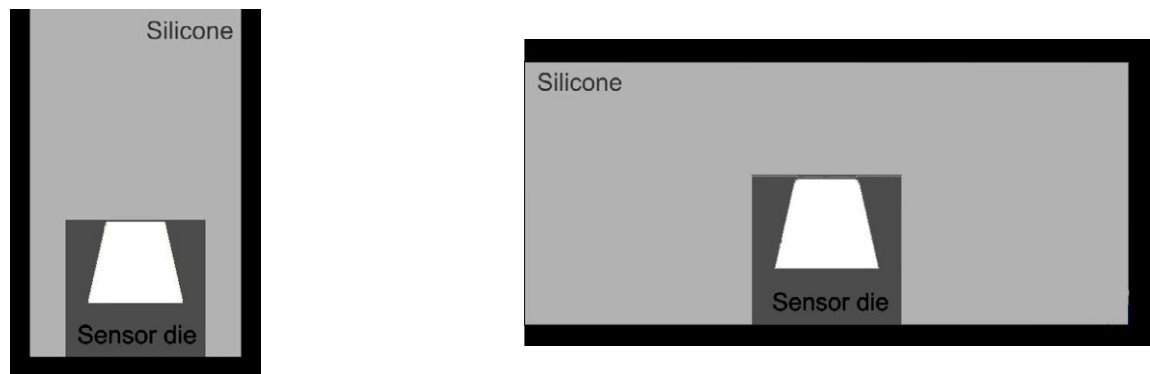


Figure 1: Schematics of the evaluated system; left: Pressure applied from top; right: Pressure applied from the side

2.2. Simulation setup and verification

All simulations are carried out in Ansys, the hyperelastic and viscoelastic properties of silicone are simulated with a combined Maxwell-Weichert and Mooney-Rivlin model.

The Maxwell-Weichert model incorporates a relaxation of a viscoelastic material over time³. Segments of different length with varying contribution result in a time distribution. The Mooney-Rivlin solid model³ considers the hyperelastic properties of the silicone. It can vary in complexity with two to nine parameters. As our experiments pointed out, the simple two-parameter model is not sufficient for simulating pressure or the compression behavior of the silicone. The five parameter model based on deformation energy however is adequately used with parameters obtained from Meier et al.⁴. As no data was available for the silicone Med-6015, which is most commonly used in medical products^{1,2,5,6} the relevant parameters were approximated with measurements of Young's modulus.

For evaluation of the amplitude reduction caused by the silicone, the changes of resistances on the membrane are observed. Deformation of the membrane reshapes the areas of the strain gauges, which causes a change in resistance. The four resistors on the membrane form a Wheatstone bridge and the measured signal is the bridge voltage. With the changes of the resistances the relative change of the bridge voltage and thus the amplitude reduction can be calculated.

A test series according to the setup in the simulation was carried out. Figure 2 shows measured data of an exemplary assembly. As idealized proportions were selected for the first design, perfectly assembled systems show almost no effects due to encapsulation.

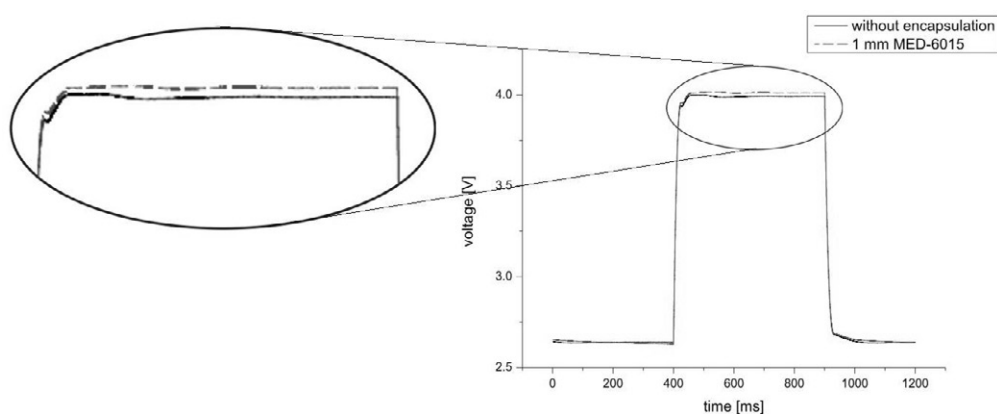


Figure 2: Sensor signal before and after encapsulation, exemplary measurement

3. Results

With the simulation the influence of different parameters on the on the measured pressure signal were evaluated. Some of the presented structures were assembled to crosscheck the simulation and within the tolerance of a few percent they all matched the simulation data.

3.1. Variation of geometry

At first a variation in geometry was evaluated. The structure shown in figure 1, left side, was varied in width and height. In table 1 it can be seen, that the amplitude reduction is increasing with increasing height. This is basically due to the worsening aspect ratio of width to height. A lot of the energy put into the system by the applied pressure wears off at the border between silicone and spacer. Missing fixation between silicone and spacer leads to almost no amplitude reduction, but this would usually be no option in practice, because on the one hand it is impracticable to assemble and on the other hand the main aspect of sealing the sensor unit from environmental influences would be no more existent. The dependency between the amplitude reduction and the aspect ratio is some sort of exponential drop, as pointed out in figure 3.

Table 1. Calculated amplitude reduction of different silicones for different aspect ratios (width to height).

Silicone height	Silicone diameter	Aspect ratio width:height	Silicone type		
			Med-6015	Med-4930	Med-4950
1 mm	2 mm	2.00	4.6 %	2.1 %	3.2 %
1 mm	1 mm	1.00	6.2 %	5.9 %	6.2 %
3 mm	1 mm	0.33	26.6 %	25.6 %	26.6 %
5 mm	1 mm	0.20	57.2 %	54.5 %	57.2 %

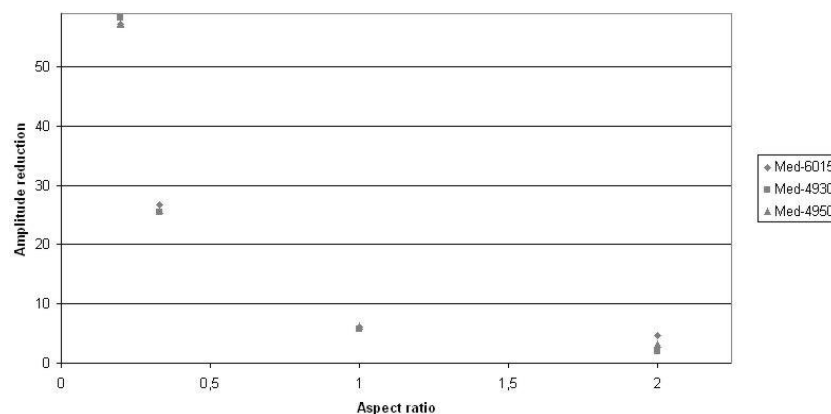


Figure 3: Calculated amplitude reduction of different silicones for different aspect ratios (width to height).

A completely different geometry as in figure 1, right side, was evaluated to show the effect of pressure applied to the system from the side wall of a sensor die. The amplitude reduction is remarkably higher than in the basic setup, but still within measurable range (see table 2). A remarkable conclusion was observed on this particular setup by varying this setup. The sensor die was sunk in the base PCB until the membrane was equal to the border silicone side wall. As long as the distance above the membrane of the sensor is kept alike, amplitude reduction stays fairly constant. The pressure applied to the side wall of the sensor deforms the fairly hard die only by nanometers. A deformation of the die this small does not affect the sensor membrane enough to alter the measured signal.

Table 2. Calculated amplitude reduction of different silicones, pressure applied from one side of the sensor.

Silicone height	Silicone diameter	Aspect ratio width:height	Silicone type		
			Med-6015	Med-4930	Med-4950
1 mm	1 mm	1.00	21.12 %	18.99 %	29.45 %

3.2. Assembly Defects

For a full evaluation of assembled systems, assembly defects have to be considered in the simulation as well. Due to non-perfect silicones, small variations in the Young's modulus might occur. Those areas of defects have been implemented in the simulation. The far most extreme defect would be an entrapped air bubble in the silicone. Of course this is to be avoided during assembly, but due to good reproducibility in assembly and simulation an air bubble was chosen to demonstrate the capabilities of the developed simulation platform.

In the presented example the air bubble was placed inside a spacer of 3 mm in diameter and a height of 5 mm. The diameter was 1.6 mm, thus reaching about half way over the sensor with a distance of 0.5 mm to the sensor membrane. Comparing the simulated and measured data a similar range of signal reduction is obtained (figure 4). Simulation of the exact offset shift is impossible because each assembly shows a different shift. This fact will be compensated by a calibration of the encapsulated system and does not affect signal quality.

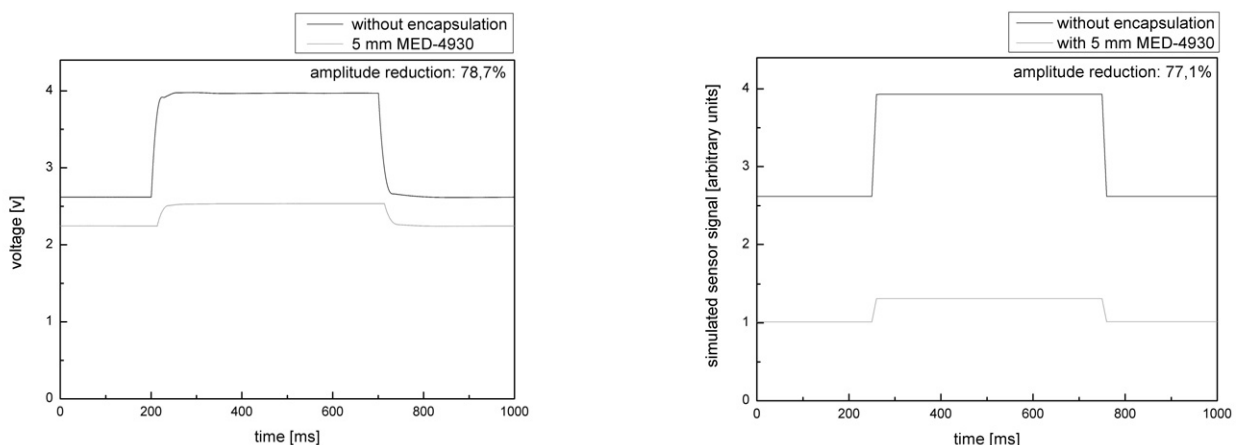


Figure 4: Sensor signal before and after encapsulation with air bubble as assembly defect; left: measured data; right: simulated data

4. Summary and outlook

A simulation platform was successfully established and verified. First results of dependencies of encapsulation on the signal of pressure sensors could be presented. In the near future, complete pressure sensor assemblies will be evaluated and presented. The simulation setup will make it possible to modify assembly geometries in order to optimize sensor reactions to pressure transfer in different silicones.

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